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The effects of two equal-volume training protocols upon strength, body composition and salivary hormones in male rugby union players

AUTHORS: Crewther BT[1], **Heke TOL**[2], **Keogh JWL**[2,3,4]

[1] Institute of Sport – National Research Institute, Warsaw, Poland
[2] Sports Performance Research Institute New Zealand, School of Sport and Recreation, Auckland University of Technology, Auckland, New Zealand
[3] Faculty of Health Sciences and Medicine, Bond University, Australia
[4] Cluster for Health Improvement, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast

Corresponding author:
Blair Crewther
Department of Endocrinology
Institute of Sport
01-982 Warsaw
Poland
Email: blair.crewther@gmail.com

ABSTRACT: This study examined the effects of two equal-volume resistance-training protocols upon strength, body composition and salivary hormones in male rugby union players. Using a crossover design, 24 male rugby players completed a 4-week full-body (FB) and split-body (SB) training protocol of equal volume during the competitive season. One repetition maximum (1RM) strength, body composition via skinfold measurements and salivary testosterone (T) and cortisol (C) concentrations were assessed pre and post training. The FB and SB protocols improved upper (7.3% and 7.4%) and lower body 1RM strength (7.4% and 5.4%), whilst reducing body fat (-0.9% and -0.4%) and fat mass (-5.7% and -2.1%), respectively (all $p \leq 0.021$). The SB protocol elevated T (21%) and C (50%) concentrations with a higher T/C ratio (28%) after FB training (all $p \leq 0.039$). The strength changes were similar, but the body composition and hormonal results differed by protocol. Slope testing on the individual responses identified positive associations ($p \leq 0.05$) between T and C concentrations and absolute 1RM strength in stronger (squat 1RM = 150.5 kg), but not weaker (squat 1RM = 117.4 kg), men. A short window of training involving FB or SB protocols can improve strength and body composition in rugby players. The similar strength gains highlight training volume as a key adaptive stimulus, although the programme structure (i.e. FB or SB) did influence the body composition and hormonal outcomes. It also appears that 1RM strength is associated with individual hormonal changes and baseline strength.

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INTRODUCTION

Resistance exercise is a well-established method of training for inducing muscle hypertrophy and/or performance (e.g. strength, power, strength endurance) improvements in both athletic and non-athletic populations [1, 2]. For athletes, resistance-based training is also used to compliment or supplement more sport-specific training methods. Important programme variables to consider when prescribing resistance exercise includes the number of exercises performed, loading intensity, as well as exercising repetitions, sets and training frequency [1, 2], which can all be modified in some capacity to emphasize different adaptations. Modifications in these variables can also influence resistance-training volume as a more global stimulus for adaptation.

The importance of training volume is supported by research demonstrating greater gains in muscle hypertrophy and/or strength when performing 2 or more sets (per exercise) compared to 1 set [3-5]. Also, meta-analyses indicate greater strength and hypertrophy gains when performing multiple set training (vs. single sets) in both trained and untrained groups [6, 7], although untrained individuals appear to be more sensitive to exercising volume up to a certain threshold than trained individuals [7]. In other words, training produces larger effect sizes in untrained than resistance-trained individuals and this response is more pronounced when up to 4 sets per exercise are performed. Consequently, to develop a true understanding of the efficacy of different resistance-training protocols and how to best achieve specific adaptations requires training volume to be equated in some manner, whilst maintaining the specific characteristics of the training methods of interest.

Many studies have equated training volume when examining the effects of different workout frequencies [8, 9], periodization models [3, 10] and loading protocols [11], as well as comparing differences in full-body (FB) and split-body (SB) training [12]. For untrained populations, it appears that training volume is more important for improving muscle size and strength than other programmable features [8, 9, 12], but for trained individuals the results are mixed [3, 10, 11].

Research interpretation is limited by factors such as small sample size (≤ 10 per group) and variability in training backgrounds. To our knowledge, no studies have been conducted on a larger (>20) cohort of concurrently-training males who arguably represent the majority of athletes using resistance exercise as an adjunct training method. For this paper, concurrent training refers to participation in resistance exercise and sport-specific conditioning across the training week.

Testosterone (T) and cortisol (C) play important roles in mediating training adaptation with one or more mechanisms involved, such as muscle and motor unit development, emotional and behavioural changes, and mobilization of metabolic resources [13]. Whilst some work on concurrently-training athletes have reported increases in resting T and C levels with performance improvements [14, 15], others have observed performance gains in the absence of any hormonal change [16-18]. This linkage may however be better detected on an individual level amongst athletic populations [13], but with 2 important caveats; first, these relationships might depend on subject strength levels or training experience [13, 15, 19] and; second, their detection (or lack thereof) might also reflect the analytical approach and whether individual differences or changes are compared [15]. Addressing these issues within the same framework would provide greater insight into the role of T and C in mediating adaptations in athletic populations.

This study sought to compare the effect of 2 equal-volume training protocols (FB and SB) upon strength, body composition and salivary hormones in strength-trained, rugby union players. We hypothesized that FB and SB training would promote positive changes in strength and body composition. Given the relative importance of training volume, we also hypothesized that the adaptive changes would be of similar magnitude. A secondary aim was to examine the influence of the hormonal milieu on strength and body composition adaptations, by looking at these relationships between individuals (i.e. correlational testing of individual differences) and within individuals (i.e. slope analyses on individual changes), with the latter approach extended to include comparisons between stronger and weaker athletes.

MATERIALS AND METHODS

Subjects. Twenty-four males (mean age 29.8 ± 6.8 years; height 179.5 ± 7.9 cm; body mass 92.9 ± 12.2 kg) with at least 2 years of resistance-training experience (3-4 times per week) were recruited. They were members of a senior rugby union team playing in a premier club competition in New Zealand. The players were in their in-season competitive phase which involved 1 rugby union game, 3 resistance-training sessions (as part of this study) and 2 rugby-specific training sessions per week. All participants were informed of the experimental risks and signed informed consent before the study commenced. The experimental procedures were performed in accordance with the ethical standards of the Helsinki Declaration and approved by the Auckland University of Technology Ethics Committee, New Zealand (number 09/125).

Resistance-training protocols

A randomized, crossover design was used to test the study hypotheses. The participants were matched (according to initial strength levels) into 2 groups to complete either a 4-week FB or a 4-week SB training protocol. The groups then crossed over to complete the other training protocol after an 8-week washout period. During this interim period, the athletes maintained their normal club training that focused primarily on skill and fitness conditioning, but all forms of resistance training were avoided. This step was taken to ensure that there were no carry-over effects from the first training block to the second training block, irrespective of the protocol completed.

Both training approaches involved 3 weekly sessions (Monday, Wednesday and Friday) completed between 1600 to 1800 hours. Training involved 8 repetition maximum lifts for selected exercises, performed for 3-6 sets with rest periods of 60-90 seconds between sets and exercises. In the FB protocol, all muscle groups were exercised during each of the 3 weekly training sessions, while in the SB protocol only a sub-set of the muscle groups was exercised during each session. The prescribed exercises included; back squats, leg curls, leg press, bench press, bent-over row, pull downs, shoulder press, bicep curls and calf raises. To equate for training volume, the total number of repetitions prescribed each week were identical (i.e. FB training = 21 exercises, 2-3 sets × 8 repetitions; SB training = 13 exercises, 3-6 sets × 8 repetitions) [8, 12, 20]. The 2 protocols are commonly used in research and practice [1, 12] and these were incorporated into the weekly schedule of the study population to improve the ecological validity of our findings. A standard warm-up was performed before all training sessions comprising of basic exercises performed with increasing intensities and stretching of the major muscle groups [18], with the athletes self-selecting the intensity and duration of stretching.

Strength assessment

The strength, body composition and hormonal assessments were completed within 3 days before and after each training phase. Testing was conducted after a full days rest, so that the athletes had a 48-hour rest period from their last training session. They were also informed to get at least 7-8 hours sleep the night before each assessment. Testing for back squat (SQ) and bench press (BP) 1 repetition maximum (1RM) strength was conducted using published guidelines [21, 22]. A standard warm-up was performed beforehand involving low-intensity lifts and stretching. For the SQ test, the athlete stood under a barbell that was resting on the upper back and shoulders, with their feet positioned shoulder width apart. They then squatted down on the eccentric phase so that the upper thigh was parallel to the ground, before pushing up on the concentric phase. For the BP test, the athletes lay supine on a flat bench and extended the arms out to reach the barbell using a shoulder grip position. The barbell was lowered during the eccentric phase (to lightly touch the chest), before pushing the load up during the concentric phase. The athletes were monitored to ensure that excessive arching of the back was avoided during the eccentric and concentric phases. The speed of movements on the eccentric phase (both exercises) was under self control, whereas the concentric phase was limited by the weight of the load lifted. A 4-minute rest period was prescribed between all 1RM attempts to ensure adequate recovery.

Body composition assessment

Body composition was assessed via skinfold measurements taken by a qualified anthropometrist. The sum of 4 skinfolds (i.e. subscapular, suprailliac, biceps, triceps) was converted to a body fat (BF) percentage using a common prediction formula [23]. The technical errors of measurement (%) were as follows; subscapular (2.2%), iliac crest (1.7%), biceps (3.1%) and triceps (2.5%). Fat-free mass (FFM) was calculated by subtracting fat mass (FM) from total body mass (BM), measured to the nearest 0.1 kg using electronic scales.

Hormone assessment

Saliva samples (1 mL) were collected immediately prior to the strength assessments, before and after each 4-week training block. Sampling occurred between 1600 and 1800 hours to control for circadian variation [24]. The samples were collected in sterile containers by passive drool and stored at -20°C before assay. Due to the afternoon assessments, the athletes did not fast on these days and we wanted to assess their abilities under normal conditions, which included meals throughout the day. However, they were told to maintain a similar diet in the morning before all testing sessions. To prevent saliva contamination, they were told to refrain from taking hot drinks and consuming any food 1-2 hours before sampling [24]. The samples were assayed in duplicate for T and C concentrations using diagnostic kits (Diagnostic Systems Laboratories Inc, USA). Testosterone assay sensitivity was 1 $\text{pg}\cdot\text{mL}^{-1}$ and C assay sensitivity was 0.05 $\text{ng}\cdot\text{mL}^{-1}$ with inter-assay coefficients of variation of < 10% for both hormones.

Statistical analyses

The hormonal data were log-transformed before analysis to normalize data distribution and reduce non-uniformity bias. Data are presented back-transformed in their original units. Changes scores in the strength, body composition and hormonal variables were calculated (post – pre training expressed as a percent change) and paired T-tests were used to examine the within-group changes and between-group differences in these outcomes. Where appropriate, 95% confidence intervals (CI) are presented as an estimate of the population effect. To test the hormonal associations with the strength and body composition variables, the individual differences in these outcomes were first examined using Pearson correlations. Next, all data were pooled to examine the linkage between the individual parameter changes, based on individual slope patterns and T-test analysis of the group mean from zero [25]. This included analysis of stronger and weaker participants. Inclusion into the stronger and weaker groups was based on a simple median split of the SQ 1RM data (i.e. 12 highest values = stronger men, 12 lowest values = weaker men) [15], after the results from all testing sessions were averaged. This allowed us to determine which individuals were consistently stronger or weaker over time. The level of significance was set at $p \leq 0.05$.

RESULTS

Initial testing revealed no significant pre-training differences (SB vs. FB) in SQ 1RM, BP 1RM, BM, BF, FM or FFM. However, we did find lower C levels ($p = 0.035$) and a higher T/C ratio ($p = 0.036$) prior to SB training, compared to FB training. The SB and FB protocols both promoted significant (all $p < 0.001$, Table 1) improvements in SQ 1RM (SB 95% CI = 4.0% to 6.8%; FB 95% CI = 5.6% to 9.3%) and BP 1RM (SB 95% CI = 5.6% to 9.3%; FB 95% CI = 5.6% to 9.0%), but no between-group differences were identified. There were no significant changes in BM, but we did find decreases in BF (SB

TABLE I. Strength, body composition and hormonal outcomes in response to the full-body and split-body resistance-training protocols (n = 24). Data are presented as means ± SD.

	Full-body training			Split-body training		
Variables	Pre-training	Post-training	% change	Pre-training	Post-training	% change
BP 1RM (kg)	102.6 ± 18.3	109.9 ± 18.8	7.3 ± 4.1**	103.1 ± 15.8	109.6 ± 16.2	7.4 ± 4.5**
SQ 1RM (kg)	128.6 ± 23.6	137.8 ± 22.7	7.4 ± 4.5**	131.1 ± 19.6	138.4 ± 21.5	5.4 ± 3.4**
BM (kg)	93.3 ± 11.0	93.2 ± 9.5	0.0 ± 1.8	93.4 ± 9.7	93.2 ± 9.3	-0.1 ± 0.9
BF (%)	18.5 ± 4.7	17.6 ± 4.7	-0.9 ± 0.8**	17.9 ± 4.6	17.5 ± 4.3	-0.4 ± 0.6**#
FM (kg)	17.6 ± 6.2	16.6 ± 5.8	-5.7 ± 6.3**	17.0 ± 5.7	16.5 ± 5.3	-2.1 ± 4.1*#
FFM (kg)	75.7 ± 6.7	76.5 ± 5.9	1.1 ± 1.9*	76.4 ± 5.7	76.7 ± 5.6	0.4 ± 0.8*
Testosterone ($\text{pg}\cdot\text{mL}^{-1}$)	82.3 ± 38.6	89.5 ± 42.5	11.0 ± 72.0	70.5 ± 26.7	84.7 ± 30.6	21.1 ± 32.7**
Cortisol ($\text{ng}\cdot\text{mL}^{-1}$)	2.61 ± 2.49	2.30 ± 2.00	-13.4 ± 155	1.85 ± 2.10	2.40 ± 1.88	50.0 ± 120*#
T/C ratio	42.8 ± 28.8	53.6 ± 24.0	28.2 ± 74.6*	63.3 ± 46.9	48.7 ± 30.3	-19.3 ± 88.9#

Notes: BP = bench press, SQ = back squat, 1RM = one repetition maximum, BM = body mass, BF = body fat, FM = fat mass, FFM = fat-free mass, T/C ratio = testosterone to cortisol ratio. *Significant within-group change $p < 0.05$, **Significant within-group change $p < 0.01$, #Significant from full-body training $p < 0.05$.

95% CI = -0.2% to -0.7%; FB 95% CI = -0.6% to -1.3%) and FM (SB 95% CI = -0.3% to -3.8%; FB 95% CI = -3.1% to -8.1%), with increasing FFM (SB 95% CI = 0.1% to 0.7%; FB 95% CI = 0.4% to 1.9%), in both protocols (all $p \leq 0.021$). The BF and FM reductions were greater with FB training ($p = 0.015$). The SB protocol increased resting T (95% CI = 7.4% to 34.7%, $p = 0.003$) and C concentrations (95% CI = -0.2% to 100%, $p = 0.019$), whereas the T/C ratio was elevated after FB training (95% CI = -3.0% to 59.4%, $p = 0.039$). The observed changes in C and the T/C ratio differed between protocols ($p \leq 0.023$).

Correlational testing (Table 2) revealed no significant relationships between the individual differences in hormones and any other variable, apart from a weak negative relationship between the T/C ratio and FFM in response to FB training ($p = 0.030$). As a pooled dataset (Table 3), there were no significant associations between the individual hormonal changes and either the strength or body composition measures. However, after separating the participants into stronger (SQ 1RM = 150.5 ± 12.9 kg) and weaker (SQ 1RM = 117.4 ± 13.6 kg) groups, we found positive associations between the T and C concentration measures and absolute BP and SQ 1RM performance in stronger men ($p \leq 0.05$), but no associations were found in the weaker men.

DISCUSSION

This study compared the effectiveness of 2 equal-volume training protocols for promoting strength, body composition and hormonal adaptations in strength-trained rugby players. Both training methods increased 1RM strength to a similar extent and facilitated positive changes in body composition (BF, FM, FFM) after only 4 weeks. The SB training protocol also promoted elevated T and C concentrations, whereas FB training produced a higher T/C ratio. Some protocol differences in the body composition and hormonal changes were identified. Finally, we identified associations between the hormonal and strength measures, but these were only detected when the individual changes were assessed and limited to stronger men.

Supporting our initial hypothesis, FB and SB training promoted similar 1RM strength improvements, which is consistent with equal-volume studies comparing training methods of moderate duration (6-10 weeks) in untrained [8, 9, 12] and recreationally-trained groups [10]. Other equal-volume studies on weight-trained popula-

TABLE 2. Correlations between the individual differences in hormones and the strength and body composition outcomes across each training protocol (n = 24).

Variables	Full-body training			Split-body training		
	Testosterone	Cortisol	T/C	Testosterone	Cortisol	T/C
BP 1RM	-0.03	-0.09	0.13	-0.22	-0.07	-0.18
SQ 1RM	0.26	0.21	-0.09	0.17	0.20	-0.17
BM	-0.08	0.11	-0.26	0.10	0.29	-0.31
BF	-0.14	-0.01	-0.11	0.26	0.19	-0.12
FM	-0.29	-0.23	0.11	0.18	0.22	-0.20
FFM	0.10	0.32	-0.44*	-0.09	0.15	-0.22

Note: BP = bench press, SQ = back squat, 1RM = one repetition maximum, BM = body mass, BF = body fat, FM = fat mass, FFM = fat-free mass, T/C = testosterone to cortisol ratio. *Significant correlation $p < 0.05$.

TABLE 3. Slope testing between the individual changes in hormones and the strength and body composition outcomes across both training protocols. Data are presented as means ± SD.

Predictor	Predicted	All (n = 24)	Stronger (n = 12)	Weaker (n = 12)
Testosterone (pg·mL^{-1})	BP 1RM (kg)	1.98 ± 7.54	3.12 ± 4.83*	0.51 ± 10.2
	SQ 1RM (kg)	2.61 ± 7.79	5.39 ± 6.31*	-0.95 ± 7.87
	BM (kg)	-0.76 ± 3.54	-0.48 ± 2.27	-1.09 ± 4.92
	BF (%)	-1.35 ± 4.76	-0.92 ± 1.82	-1.85 ± 7.30
	FM (kg)	-1.44 ± 5.41	-0.87 ± 1.95	-2.10 ± 8.32
	FFM (kg)	0.67 ± 2.37	0.39 ± 0.89	1.00 ± 3.63
Cortisol (ng·mL^{-1})	BP 1RM (kg)	0.83 ± 9.79	4.45 ± 6.36*	-3.27 ± 11.7
	SQ 1RM (kg)	2.30 ± 13.0	8.35 ± 13.3*	-4.57 ± 8.24
	BM (kg)	0.31 ± 1.25	0.18 ± 1.29	0.45 ± 1.23
	BF (%)	-0.11 ± 0.93	-0.21 ± 0.94	0.02 ± 0.93
	FM (kg)	0.01 ± 1.05	-0.15 ± 0.96	0.19 ± 1.15
	FFM (kg)	0.30 ± 0.92	0.33 ± 1.02	0.26 ± 0.82

Note: BP = bench press, SQ = back squat, 1RM = one repetition maximum, BM = body mass, BF = body fat, FM = fat mass, FFM = fat-free mass. *Significant slope $p \leq 0.05$.

tions have demonstrated greater strength benefits with a 3-day (vs. 1 day) a week training approach [20], performing specific strength (vs. bodybuilding) training [11] and employing undulating (vs. linear) periodization [3]. The different outcomes reported in these studies [3, 11, 20] could be explained by the design of the training week and the individual sessions within it, combined with longer training periods (8-12 weeks) and prior training experience of the assessed populations, although none of these cohorts were regularly participating in another sport. So it appears that, as individuals adapt to the training stimulus, other variables can be manipulated to induce further strength adaptations, even when training volume is kept constant.

Our weekly strength changes in SQ (1.9%) and BP (1.4-1.8%) 1RM are comparable to other relatively short duration (4-6 week) training studies involving rugby union players [17, 18, 26] and longer duration research on other athletic groups [5, 22, 27]. This indicates that reasonable changes in upper and lower body strength can be achieved by experienced athletes in as little as 4 weeks with continual gains over longer periods through appropriate training. Slightly larger weekly gains (up to 3%) were demonstrated by elite rugby players [18, 26] when completing 3-7 training sessions per week. Likewise, in other team-sport athletes, a high-volume, 3 day a week training programme promoted greater strength gains than moderate and low volume training [22]. These findings confirm the importance of weekly training volume as a more global stimulus for adaptive change; however, there is likely to be an upper volume limit before performance plateaus and subsequent reductions will occur.

The 2 training protocols improved various aspects of body composition (i.e. BF and FM decreased, FFM increased), with FB training producing more favourable BF and FFM outcomes. This could be due to the activation of more muscle groups per training session. Studies examining training programmes using an equal-volume format have reported comparable decreases in BF [10, 12, 20] and/or increases in FFM [8, 20]. The magnitude of change (± 4%) is also consistent with reports on concurrently-training athletes [17, 26, 28]. It is important to consider technical error in the skinfold measurements (up to 3%) when interpreting our results, particularly as FM and FFM were derived from the BF estimates. For concurrently-training athletes, one must also consider the combined effect of resistance training and other exercise forms (e.g. skills training, recovery sessions, competition), as well as dietary factors that were not strictly controlled. Still, these data indicate that small to moderate increases in FFM can occur in conjunction with a reduction in FM and BF during short, medium or long-term training programmes in either untrained or trained populations.

The SB protocol increased T and C concentrations and the FB protocol promoted a higher T/C ratio, so that the C and T/C responses to these protocols differed, although training volume was matched. No other research has compared the hormonal responses to equal-volume training in team-sport athletes, but observational work on rugby players [14] and a mixed group of athletes from different sports [15] revealed similar patterns of T and C change. Despite promoting different hormonal profiles, the FB and SB protocols still produced strength gains of similar magnitude, so it is unlikely that the hormonal changes that occurred on a group level directly contributed to the observed strength gains. In fact, many studies on concurrently-training athletes have failed to demonstrate a hormonal change despite improvements in physical performance [16, 29, 30], including research on rugby players [17, 18]. We do acknowledge some protocol differences in baseline C and T/C values before training commenced, perhaps arising from prior rugby union matches [31, 32] or other psychological factors (e.g. work and life stress) not measured.

We did find a positive association between athlete hormones and 1RM strength when the individual changes were examined. This is consistent with other longitudinal studies [14, 15, 18], but the relationships in this work were limited to stronger men. Supporting this finding, a strong correlation ($r = 0.92$) was found between pre-session T levels and BS strength in very strong men (squatting > 2 times their BM), but in less strong men (squatting < 1.9 times their BM) this relationship was weak ($r = 0.35$) [15]. Significant hormonal relationships with other training outcomes have also been demonstrated in stronger, elite-level rugby players [14, 18, 21], but not in club-level players [17]. These data suggest that individual variances (in particular the changes) in the hormonal milieu might play a greater role in mediating adaptive physiology as athletes transition from a recreational to a more highly-trained status, which is likely to parallel changes in their baseline physical abilities [13, 15].

The observed associations highlight the value of undertaking a more frequent sampling schedule to characterize hormone dynamics and link individual changes to adaptive gains in physical performance, which may not (as we found) reflect overall group trends. This type of data arguably provides more meaningful information for athlete assessments, training evaluation, developing targeted strategies and general monitoring in sport. Our data further suggests that the grouping of athletes of mixed strength abilities may bias predictive results in a manner that does not reflect sub-groups within a population [19]. The prediction results are still limited by the frequency and timing of the assessments completed herein, and we are unable to establish the true nature of these associations (i.e. cause or effect). Other limitations of this study include the lack of a non-exercising control group and the relatively short period of training.

CONCLUSIONS

The current findings indicate that a short dedicated window of training, involving FB or SB protocols, can improve strength and body composition in male rugby players during the competitive season. The similar strength gains highlight training volume as a key stimulus for adaptation, although programme structure (i.e. FB or SB) did influence the body composition and hormonal outcomes. Our results further suggest that the expression of 1RM strength is associated with changes in individual hormones over time and baseline strength abilities.

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REFERENCES

1. Ratamess NA, Alvar BA, Evetoch TK, Housh TJ, Kibler BW, Kraemer WJ, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41(3):687-708.
2. Crewther BT, Cronin J, Keogh J. Possible stimuli for strength and power adaptation: acute mechanical responses. Sports Med. 2005;35(11):967-89.
3. Rhea MR, Ball SD, Phillips WT, Burkett LN. A comparison of linear and daily undulating periodised programs with equated volume and intensity for strength. J Strength Cond Res. 2002;16:250-5.
4. Paulsen G, Myklestad D, Raastad T. The influence of volume of exercise on early adaptation to strength training. J Strength Cond Res. 2003;17(1):115-20.
5. Kramer JB, Stone MH, O'Bryant HS, Conley MS, Johnson RL, Nieman DC, et al. Effects of single vs. multiple sets of weight training: Impact of volume, intensity and variation. J Strength Cond Res. 1997;11(3):143-7.
6. Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. J Strength Cond Res. 2010;24(4):1150-9.
7. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. Med Sci Sports Exerc. 2003;35(3):456-64.
8. Candow DG, Burke DG. Effect of short-term equal-volume resistance training with different workout frequency on muscle mass and strength in untrained men and women. J Strength Cond Res. 2007;21(1):204-7.
9. Gentil P, Fischer B, Martorelli AS, Lima RM, Bottaro M. Effects of equal-volume resistance training performed one or two times a week in upper body muscle size and strength of untrained young men. J Sports Med Phys Fit. 2014:Epub ahead of print.
10. Buford TW, Rossi SJ, Smith DB, Warren AJ. A comparison of periodization models during nine weeks with equated volume and intensity for strength. J Strength Cond Res. 2007;21(4):1245-50.
11. Schoenfeld BJ, Ratamess NA, Peterson MD, Contreras B, Sonmez GT, Alvar BA. Effects of different volume-equated resistance training loading strategies on muscular adaptations in well-trained men. J Strength Cond Res. 2014;28(10):2909-18.
12. Arazi H, Asadi A. Effects of 8 weeks equal-volume resistance training with different workout frequency on maximal strength, endurance and body composition. Int J Sport Sci Eng. 2011;5(2):112-8.
13. Crewther BT, Cook C, Cardinale M, Weatherby RP, Lowe T. Two emerging concepts for elite athletes: The short-term effects of testosterone and cortisol on the neuromuscular system and the dose-response training role of these endogenous hormones. Sports Med. 2011;41(2):103-23.
14. Argus CK, Gill ND, Keogh JWL, Hopkins WG, Beaven MC. Changes in strength, power, and steroid hormones during a professional rugby union competition. J Strength Cond Res. 2009;23(5):1583-92.
15. Crewther BT, Cook CJ, Gaviglio CM, Kilduff LP, Drawer S. Baseline strength can influence the ability of salivary free testosterone to predict squat and sprinting performance. J Strength Cond Res. 2012;26(1):261-8.
16. Potteiger JA, Judge LW, Cerny JA, Potteiger VM. Effects of altering training volume and intensity on body mass, performance, and hormonal concentrations in weight-event athletes. J Strength Cond Res. 1995;9(1):55-8.
17. Crewther BT, Heke T, Keogh JWL. The effects of a resistance-training program on strength, body composition and baseline hormones in male athletes training concurrently for rugby union 7's. J Sports Med Phys Fit. 2013;53:34-41.
18. Crewther BT, Lowe T, Weatherby RP, Gill N. Prior sprint cycling did not enhance training adaptation, but resting salivary hormones were related to workout power and strength. Eur J Appl Physiol. 2009;105(6):919-27.
19. Crewther BT, Kilduff LP, Cook CJ, Cunningham DJ, Bunce P, Bracken RM, et al. Relationships between salivary free testosterone and the expression of force and power in elite athletes. J Sports Med Phys Fit. 2012;52(2):221-7.
20. McLester JR, Bishop P, Guilliams ME. Comparison of 1 day and 3 days per week of equal-volume resistance training in experienced subjects. J Strength Cond Res. 2000;14(3):273-81.
21. Crewther BT, Lowe T, Weatherby RP, Gill N, Keogh J. Neuromuscular performance of elite rugby union players and relationships with salivary hormones. J Strength Cond Res. 2009;23(7):2046-53.
22. Naclerio F, Faigenbaum AD, Larumbe-Zabala E, Perez-Bibao T, Kang J, Ratamess NA, et al. Effects of different resistance training volumes on strength and power in team sport athletes. J Strength Cond Res. 2013;27(7):1832-40.
23. Durnin JV, Rahaman MM. The assessment of the amount of fat in the human body from measurements of skinfold thickness. Brit J Nutri. 1967;21:681-9.
24. Hackney AC, Viru A. Research methodology: endocrinologic measurements in exercise science and sports medicine. J Athl Training. 2008;43(6):631-9.
25. Hopkins WG. A spreadsheet for analysis of straightfoward controlled trials 2003 [cited 2012 4th May]. Available from: http://www.sportsci.org/jour/03/wghtrials.htm.
26. Argus CK, Gill N, Keogh J, Hopkins WG, Beaven MC. Effects of a short-term pre-season training programme on the body composition and anaerobic performance of professional rugby union players. J Sports Sci. 2010;28(6):679-86.
27. Izquierdo M, Ibañez J, Gonzalez-Badillo J, Häkkinen K, Ratamess NA, Kraemer WJ, et al. Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. J Appl Physiol. 2006;100(5):1647-56.
28. Kraemer WJ, Ratamess N, Fry AC, Triplett-McBride T, Koziris LP, Bauer JA, et al. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. Am J Sports Med. 2000;28(5):626-33.
29. Ostrowski JK, Wilson J, Weatherby R, Murphy WP, Lyttle DA. The effect of weight training volume on hormonal output and muscular size and function. J Strength Cond Res. 1997;11(1):148 - 54.
30. Gorostiaga EM, Izquierdo M, Iturralde P, Ruesta M, Ibañez J. Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. Eur J Appl Physiol Occ Physiol. 1999;80:485-93.
31. Cunniffe B, Hore AJ, Whitcombe DM, Jones KP, Baker JS, Davies B. Time course of changes in immunoendocrine markers following an international rugby game. Eur J Appl Physiol. 2010;108:113-22.
32. West DJ, Finn CV, Cunningham DJ, Shearer DA, Jones MR, Harrington BJ, et al. Neuromuscular function, hormonal, and mood responses to a professional rugby union match. J Strength Cond Res. 2014;28(1):194-200.